NASA Phase I Project Summary

Firm: Creare Incorporated
Contract Number: NNX12CE90P
Project Title: A Multi-Environment Thermal Control System With Freeze-Tolerant Radiator

Identification and Significance of Innovation:

Future space exploration missions require advanced thermal control systems (TCS) to dissipate heat from spacecraft, rovers, or habitats to external environments. We propose to develop a lightweight, reliable TCS to effectively control cabin and equipment temperatures under widely varying heat loads and ambient temperatures. The proposed system uses freeze-tolerant radiators, which eliminate the need for a secondary circulation loop or heat pipe systems. Each radiator has a self-regulating variable thermal conductance to its ambient environment. The variable conductance will enable the TCS to maintain the cabin and equipment within a tightly controlled temperature band. The TCS uses a nontoxic working fluid that is compatible with existing lightweight aluminum heat exchangers. The TCS is lightweight, compact, and requires very little pumping power. In Phase I, we proved the feasibility of our approach through performance demonstration of a key component in the TCS system supported by detailed system design and analysis. In Phase II, we will build a freeze-tolerant radiator and it axillary component and obtain detailed test data to show its unique performance advantages during steady state and transient operation.

Technical Objectives and Work Plan:

The Phase I technical development centered on three core design tasks. (1) *Define System Specifications:* In conjunction with engineers at NASA and our collaborator, we identified reference missions to establish the relevant values for operating conditions (e.g., operating loads, heat sink temperature profiles, heat source temperatures) that will drive the TCS designs for future missions. (2) *Prototype Demonstration:* Based on the design criteria, we constructed a prototype condenser test article and demonstrated the key performance characteristics required of a self-regulating, variable-conductance, freeze-tolerant condenser. (3) *Phase II Design:* Leveraging the practical lessons learned through prototypic testing, we developed design models and refined the prototype condenser design. Additionally, CFD analyses guided the development of another low-TRL component, the liquid ejector pump, which is critical to the overall system performance. Further work focused on the identifying corrosion inhibitor additives to enable water as the working fluid in a TCS using lightweight aluminum heat exchangers.

Technical Accomplishments:

In Phase I, we worked with engineers at NASA and our collaborator to identify operating prerequisites for manned spacecraft missions (e.g., Altair lunar module). Based on these technical requirements, we optimized a radiator panel with a mass per unit heat rejection competitive with state-of-the-art non-freeze-tolerant designs. To reduce the weight relative to conventional stainless steel loops, we worked with our collaborator to identify a biocide/corrosion inhibitor package that mitigates aluminum corrosion and biofilm fouling, thereby enabling an aluminum-water system. Functional performance testing using a convectively-cooled prototypical condenser tube demonstrated the operating characteristics required for a reliable, freeze-tolerant condensing system, namely (1) self-regulating thermal conductance with short transient responses to varying thermal loads, (2) effective operation in a partially frozen state, (3) fast start-up from fully frozen state, and (4) the ability to survive a fully frozen state without suffering structural damage. The successful validation of the freeze-tolerant concept in Phase I warrants further development of the TCS system in Phase II. Existing high-TRL technologies, including heat exchangers, liquid pumps, and the SWME evaporator, can be incorporated into the single-phase pumped loop with low development effort. Future development will focus on advancing the TRL of the more nascent radiator panel, ejector pump, and aluminum-water inhibitor package technologies.

NASA Application(s):

The TCS can be used in any future manned spacecraft, rovers, and habitats, with applications that include lunar, Mars, and asteroid exploration. The thermal control technology can also be used in other unmanned spacecraft, including satellites and exploration rovers.

Non-NASA Commercial Application(s):

The advanced thermal control system has applications to two-phase thermal control systems in commercial and military satellites and unmanned aircraft.

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